2015 Annual Merit Review

IBIS Associates, Inc.

Technical Cost Modeling for Vehicle Lightweighting: 40% and 45% Weight Reduction
Project ID # LM090

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June 11, 2015

Prepared for the U.S. Department of Energy, Office of Nuclear Energy
Under DOE Idaho Operations Office, Contract DE-AC07-05ID14517

Overview

Timeline

- Project Start: December 2013
- Project end: December 2014
- 100% Complete

Budget

- FY14-15 = $120 K

Barriers

- Conflicting forces between vehicle lightweighting designs and materials with economics and consumer preferences
- Lack of information on high volume, world class manufacturing costs and materials prices for many weight reduction strategies

Project Partners

- IBIS Associates, Incorporated
- Energetics Incorporated.
- Idaho National Laboratory (INL)

A. Relevance

Objective

- Develop framework and analyses to validate cost effective weight reduction of target baseline vehicle by 40%.
- Compare scenarios and identify path for most effective cost-per-pound-saved, (target $3.42/lb)
- Identify additional opportunities and requirements to achieve 45% weight reduction

Workplan

- 1.) Follow and incorporate weight savings data from DOE MMLV Mach1 and Mach 2 designs
- 2.) Review data from other high profile lightweighting initiatives
- 3.) Participate in discussions with DOE VTO, INL, MMLV, Energetics, etc. team members
- 4.) Assemble data and construct models for analysis
- 5) Report results and make recommendations

B-1. Approach: Task List

- Develop preliminary approach to achieve 40% weight reduction for BIW and chassis
- Develop TCM framework and collect relevant data
- Implement preliminary approach in the TCM and validate results (within 10 percent uncertainty)
- Adjust approach as needed and reevaluate the TCM to achieve the 40% target weight reduction and meet cost goal or less than $3.42 per pound or weight saved
- Complete 40% weight reduction draft report.
- Draft of baseline vehicle weight distribution and draft of systems costs with assumptions for internal review
- Draft of cost model showing cost effective pathway to reach mid-term goal of 45% weight reduction in a midsize passenger car
- Complete 45% weight reduction draft report.
- Complete 45% weight reduction report in format suitable for publication and/or distribution

B-2. Approach: 2013 Baseline Vehicle

(a) Chevrolet Malibu, (b) Buick LaCrosse,
(c) Chrysler 200,
(d) Ford Fusion, and (e) Honda Accord.

Photos from Edmunds.com

Midsize Baseline 2013 Internal Combustion Engine Midsize Steel Unibody	Mass (lb)	Cost ($)
Baseline	**998**	**$6,119**
Engine	345	$3,162
Energy Storage	33	$74
Fuel System	165	$364
Transmission	195	$1,199
Driveshaft/Axle	55	$177
Differential	24	$132
Cradle	62	$107
Thermal Management	33	$150
Exhaust System	50	$230
Oil and Grease	9	$81
Powertrain Electronics	22	$400
Emission Control Electronics	4	$43
	1,006	**$2,823**
BIW	717	$1,287
Closures	134	$230
Front/Rear Bumpers	20	$126
Glazing	81	$250
Paint	24	$450
Exterior Trim	8	$144
Body Hardware	18	$312
Body Sealers and Deadeners	4	$24
	663	**$1,807**
Suspension	270	$578
Braking System	163	$406
Wheels and Tires	180	$317
Steering System	49	$506
	473	**$3,370**
Instrument Panel	84	$900
Trim and Insulation	119	$390
Door Modules	50	$300
Seating and Restraints	172	$1,330
Heating, Ventilation, and Air Conditioning (HVAC)	48	$450
	112	**$1,000**
Interior Electrical	57	$400
Chassis Electrical	33	$400
Exterior Electrical	22	$200
	53	**$605**
	3305	**$15724**

B-3. Approach: Data Sources

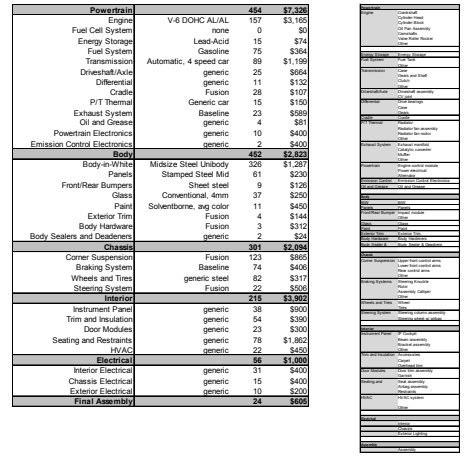
- DOE target definition
- Direct interviews with OEM and supplier engineers and designers
- Published vehicle specification data
- IBIS databases and previous cost analyses
- Vehma/Ford Fusion breakdown data
- Vehma/Ford MMLV Mach-1 and Mach-2 data
- Lotus Phase 1 lightweighting
- FEV Light-Duty Mass Reduction Cost Analysis
- Aluminum Association BIW studies
- Honda's Study & Report on NHTSA Study
- USCAR/ACC/USAMP lightweighting studies

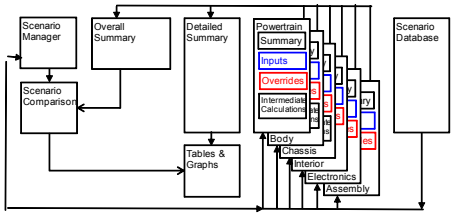
C-1. Strategy: Overview

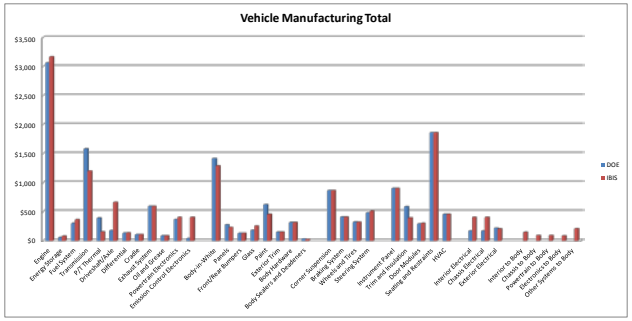
- Define Baseline
- Build Cost Model Structure
  - *System Level*
  - *Subsystems*
  - *Components*
  - *Assembly*
- Collect Lightweighting Program Data
  - *Integrate Data to Vehicle Scenarios*
- Analytical Framework
  - *Link Power, Mass, Sizing, Cost Relationships*
  - *Compare Scenario results*
  - *Identify additional weight savings needed*
  - *Establish economic requirements for cost target*

	Mass (kg/vehicle)	Cost ($/vehicle)
Powertrain	454	$7,326
Body	452	$2,823
Chassis	301	$2,094
Interior	215	$3,902
Electrical	56	$1,000
Final Assembly	24	$605
TOTAL MANUFACTURING	**1,502**	**$17,750**

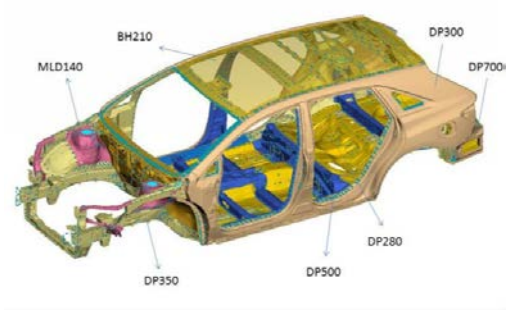
Powertrain		**454**	**$7,326**
Engine	V-6 DOHC AL/AL	157	$3,165
Fuel Cell System	none	0	$0
Energy Storage	Lead-Acid	15	$74
Fuel System	Gasoline	75	$364
Transmission	Automatic, 4 speed car	89	$1,199
Driveshaft/Axle	generic	25	$664
Differential	generic	11	$132
Cradle	Fusion	28	$107
P/T Thermal	Generic car	15	$150
Exhaust System	Baseline	23	$589
Oil and Grease	generic	4	$81
Powertrain Electronics	generic	10	$400
Emission Control Electronics	generic	2	$400
Body		**452**	**$2,823**
Body-in-White	Midsize Steel Unibody	326	$1,287
Panels	Stamped Steel Mid	61	$230
Front/Rear Bumpers	Sheet steel	9	$126
Glass	Conventional, 4mm	37	$250
Paint	Solventborne, avg color	11	$450
Exterior Trim	Fusion	4	$144
Body Hardware	Fusion	3	$312
Body Sealers and Deadeners	generic	2	$24
Chassis		**301**	**$2,094**
Corner Suspension	Fusion	123	$860
Braking System	Baseline	74	$406
Wheels and Tires	generic steel	82	$317
Steering System	Fusion	22	$506
Interior		**215**	**$3,902**
Instrument Panel	generic	38	$900
Trim and Insulation	generic	54	$390
Door Modules	generic	23	$300
Seating and Restraints	generic	78	$1,862
HVAC	generic	22	$450
Electrical		**56**	**$1,000**
Interior Electrical	generic	31	$400
Chassis Electrical	generic	15	$400
Exterior Electrical	generic	10	$200
Final Assembly		**24**	**$605**



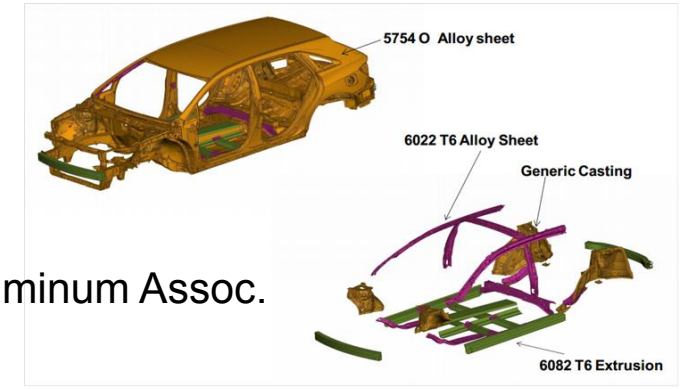




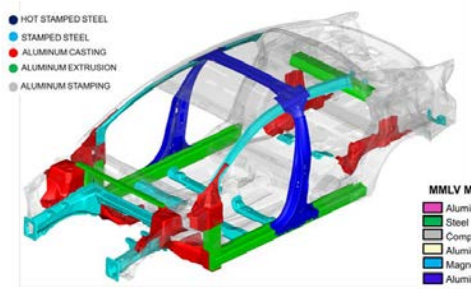
C-2. Available Lightweighting Program Data



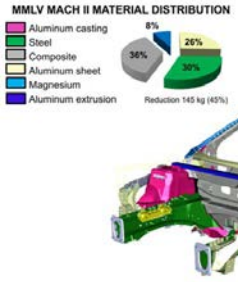
Lotus/FEV

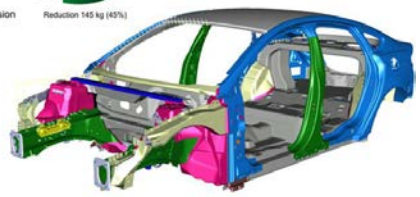


Aluminum Assoc.



MMLV Mach I





MMLV Mach II

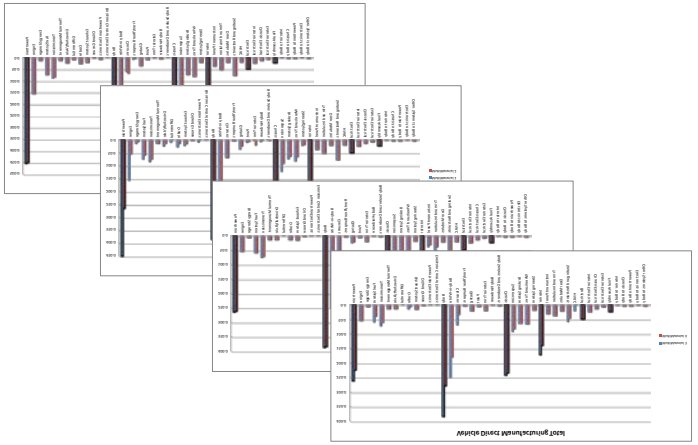
BMW i3

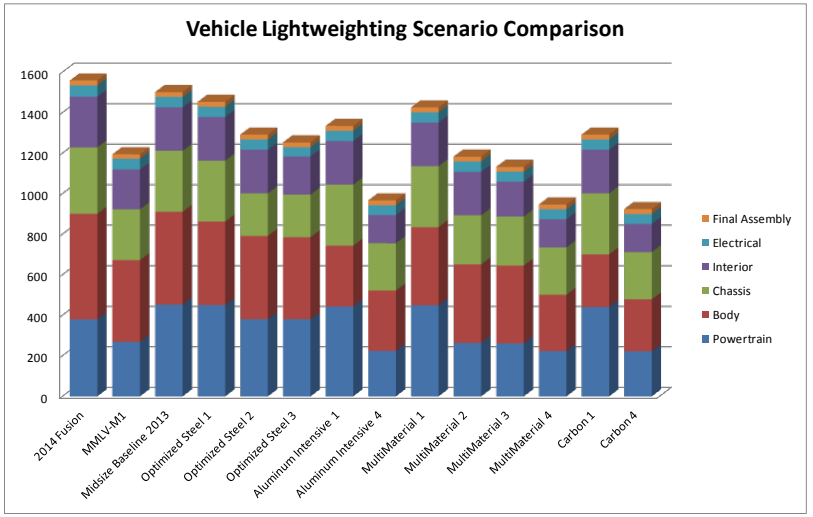
C-3. Lightweighting Technologies

- Body
  - *Ultra high strength steels*
  - *Aluminum stampings, extrusions, and castings*
  - *Carbon fiber layup (tape and roving, automated), SMC, and injection molding*
  - *Chemically toughened glass, polycarbonate*
- Powertrain
  - *Magnesium and Aluminum high pressure vacuum die casting*
  - *Carbon fiber filament winding*
  - *Increased power density from advanced engine design*
- Chassis
  - *Aluminum castings, forgings, and extrusions*
  - *Carbon fiber wheels*
- Assembly
  - *Adhesive bonding*
  - *Self piercings rivets*
  - *Friction stir welding*

C-4. Mass Reduction Analysis

- Baseline
  - *Previously defined case study, mass and cost list*
- Stage 1
  - *Body structure alternatives only (BIW, panels, bumpers)*
  - *Optimized steel, aluminum intensive, multi-material, carbon*
- Stage 2
  - *Powertrain and chassis*
- Stage 3
  - *Other body, interior, auxiliary systems*
- Stage 4
  - *"Best-in-class" from each scenario, Mach 2 MM Body*
- Stage 5
  - *Additional/speculative mass reduction to reach 45% target*





C-5. Risk Factors

- Costing performed as fully implemented, high volume processes, with automation and expected learning curve improvements (not as current developmental or low volume)
- Full detail of functionally equivalent, crashworthy designs for most advanced concepts were not available
- Potential reduced performance

Particular to carbon:

- Repairability
- Corrosion system unclear
- $/pound fiber actual vs $/lb required
- $/pound finished part actual vs required

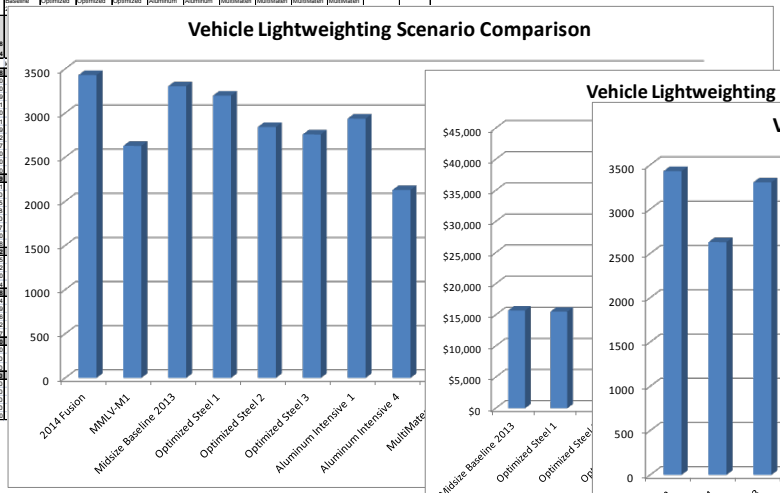
D-1. Technical Accomplishments

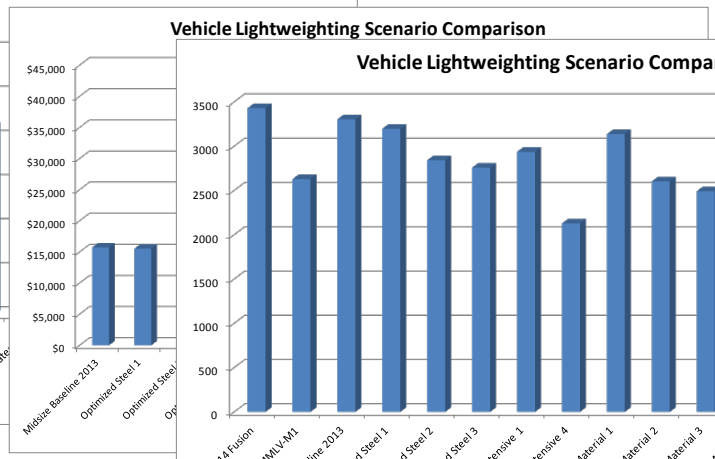
	2014 Fusion	MMLV-M1	Midsize Baseline 2013	Optimized Steel 1	Optimized Steel 2	Optimized Steel 3	Aluminum Intensive 1	Aluminum Intensive 4	Multi-Material 1	Multi-Material 2	Multi-Material 3	Multi-Material 4	Carbon 1	Carbon 4	Carbon 5	40% Reduction Target	45% Reduction Target
Lbs	3430	2629	3304	3198	2843	2758	2937	2129	3138	2604	2493	2084	2843	2034	1812	1983	1817
Lbs Saved	0	801	0	106	462	546	367	1175	167	701	812	1220	462	1271	1493	1322	1487
% wt savings	0.0%	23.4%	0.0%	3.2%	14.0%	16.5%	11.1%	35.6%	5.0%	21.2%	24.6%	36.9%	14.0%	38.5%	45.2%	40.0%	45.0%
Direct Mfg Cost			$15,724	$15,522	$15,389	$15,291	$16,070	$16,706	$16,107	$16,484	$16,833	$20,036	$21,705	$22,307	$25,211		
$3.42/lb Cost Target			$15,724	$16,087	$17,302	$17,591	$16,980	$19,744	$16,294	$18,120	$18,500	$19,896	$17,303	$20,069	$20,829	$20,244	$20,809
Project Cost of Wt. Save				-$1.90	-$0.72	-$0.79	$0.94	$0.84	$2.30	$1.09	$1.37	$3.53	$12.95	$5.18	$6.36		
Target Cost Wt. Save			$3.42	$3.42	$3.42	$3.42	$3.42	$3.42	$3.42	$3.42	$3.42	$3.42	$3.42	$3.42	$3.42		

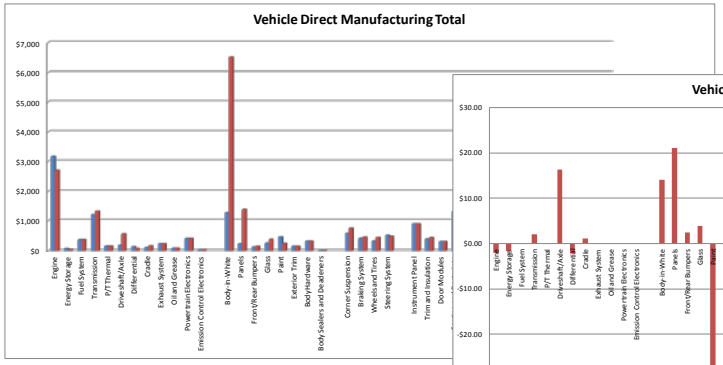
- 13 scenarios compared, at various levels of mass reduction
- Total weight saved and overall direct manufacturing cost evaluated
- Cost of weight savings compared to target
- Assessment of CF material price and composite fabrication cost required to meet 40% and 45% mass reduction targets at additional cost target of $3.42/lb-saved

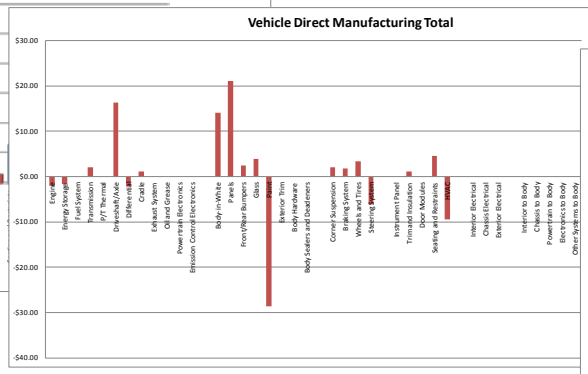
D-2. Lightweighting Cost Analysis Results

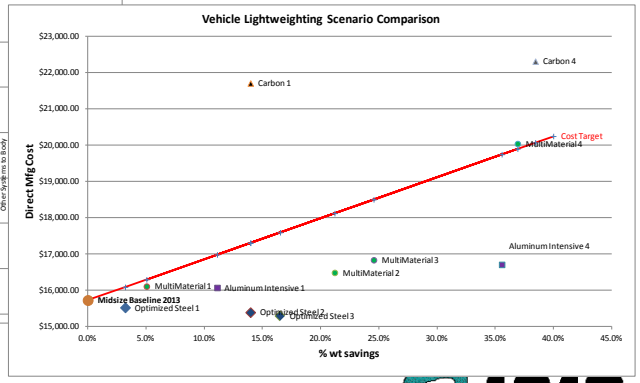
	Ford	Ford/Vehma	DOE	IBIS	IBIS	IBIS	IBIS	IBIS	IBIS	IBIS	IBIS	IBIS	IBIS	IBIS	IBIS	IBIS
	2014 Fusion	MMLV-M1	2013 Midsize Baseline	Midsize Baseline 2013	Optimized Steel 1	Optimized Steel 1	Optimized Steel 2	Optimized Steel 3	Aluminum Intensive 1	Aluminum Intensive 4	MultiMateri 1	MultiMateri 2	MultiMateri 3	MultiMateri 4	Carbon 1	Carbon 4
Total Mass (lbs)	3430	2629	3303	3304	3198											
Total Mass (kg)	1559	1195	1502	1502	1454											
				kgs												
Powertrain	380.0	288.5	491.0	461.6	460.3											
Engine	121.0	54.9	157.0	157.0	157.0											
Energy Storage	14.0	8.0	18.0	15.0	15.0											
Fuel System	67.0	59.3	64.8	74.9	74.9											
Transmission	88.0	77.0	110.4	88.8	86.1											
P/T Thermal	7.0	17.0	18.7	15.0	15.0											
Driveshaft/Axle	18.0	14.7	28.2	25.1	25.1											
Differential	1.0	0.0	12.9	10.9	10.9											
Cradle	27.0	15.0	32.8	26.2	28.2											
Exhaust System	22.0	18.3	22.7	22.7	22.7											
Oil and Grease	4.0	4.0	12.3	4.0	4.0											
Powertrain Electronics	9.0	1.8	12.9	10.0	10.0											
Emission Control Electronics	2.0	0.8	1.4	2.0	2.0											
Body	521.0	404.2	454.8	457.4	411.3											
Body-in-White	326.0	250.2	325.8	325.8	281.1											
Panels	98.0	68.8	61.0	61.0	61.0											
Front/Rear Bumpers	41.0	25.9	10.2	9.2	8.0											
Glass	36.0	24.9	22.2	36.8	36.8											
Paint	8.0	7.7	12.2	11.0	11.0											
Exterior Trim	4.0	21.4	11.1	3.7	3.7											
Body Hardware	3.0	0.0	10.2	8.0	8.0											
Body Sealers and Deadeners	5.0	3.3	2.0	1.8	1.8											
Chassis	328.0	251.6	306.7	301.2	301.2											
Corner Suspension	121.0	101.1	135.8	122.5	122.5											
Braking System	79.0	64.2	70.7	74.2	74.2											
Wheels and Tires	106.0	66.0	58.4	82.0	82.0											
Steering System	22.0	19.7	41.7	22.4	22.4											
Interior	250.0	196.2	214.7	214.8	214.8											
Instrument Panel	38.0	31.6	32.2	38.4	38.4											
Trim and Insulation	40.0	38.4	41.5	53.9	53.9											
Door Modules	50.0	42.5	30.2	22.6	22.6											
Seating and Restraints	90.0	58.4	89.1	78.2	78.2											
HVAC	32.0	25.3	21.7	21.7	21.7											
Electrical	56.0	53.0	24.0	51.0	51.0											
Interior Electrical	31.0	25.1	3.2	26.0	26.0											
Chassis Electrical	15.0	19.0	3.2	15.0	15.0											
Exterior Electrical	10.0	8.9	18.0	10.0	10.0											
Final Assembly	24.0	21.9	19.3	24.0	24.0											
Interior to Body	3.0	2.7	1.3	3.0	3.0											
Chassis to Body	6.0	5.5	2.6	6.0	6.0											
Powertrain to Body	6.0	5.5	2.6	6.0	6.0											
Electronics to Body	3.0	2.7	1.3	3.0	3.0											
Other Systems to Body	6.0	5.5	2.6	6.0	6.0											



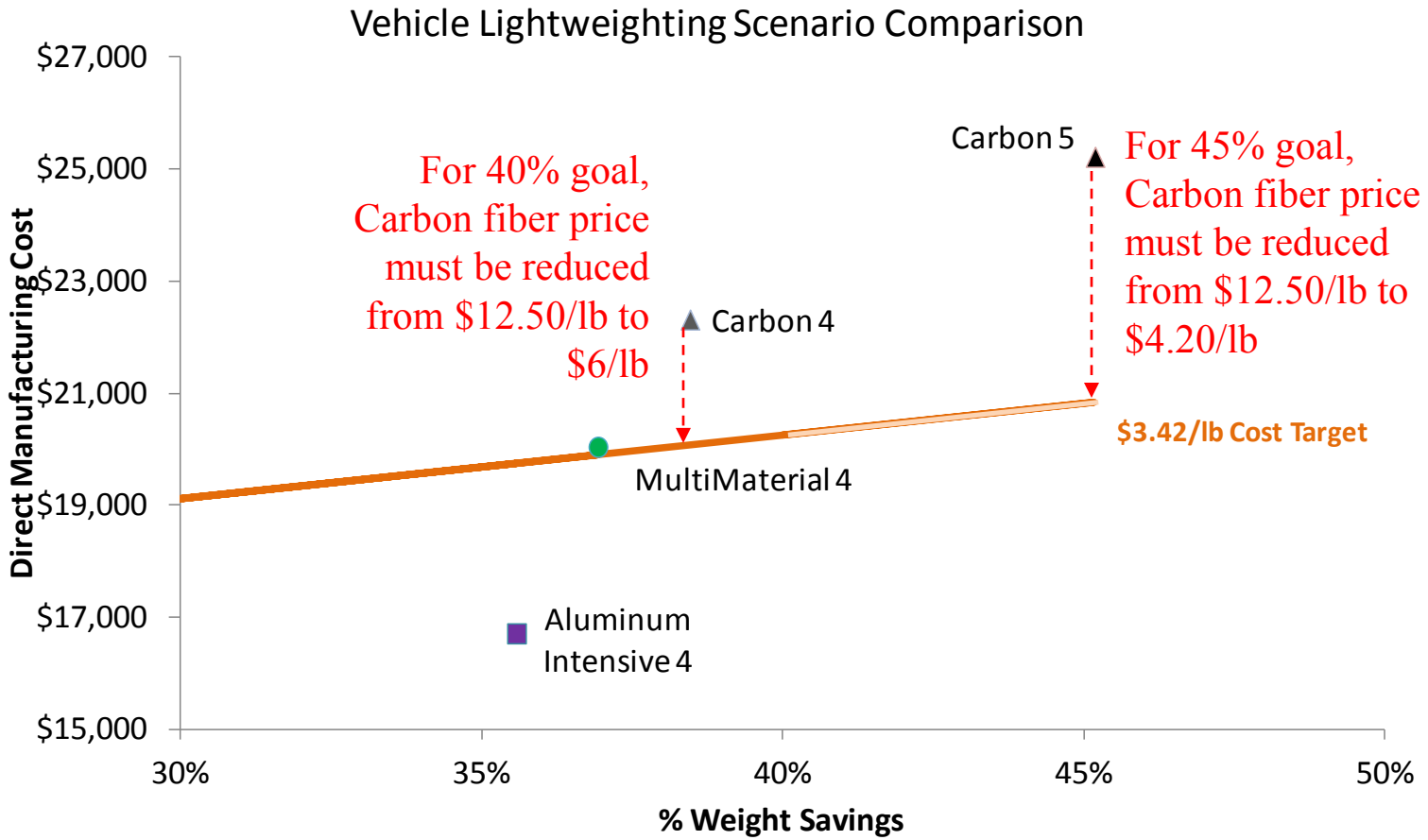








D-3. Results, CF Price Needed for Target



Costing results of advanced weight savings scenarios based on different material systems. Carbon scenarios assume optimistic projected carbon composite processing cost of $5/lb and current carbon fiber price of $12.50/lb.

E. Collaborations

- Analysis developed within IBIS Associates, Inc. and Energetics Incorporated.
- Direction and assistance from DOE
  - *Carol Schutte, Materials Technology Lead, VTO*
  - *Gerry Gibbs, Propulsion Materials, VTO*
  - *Data, commentary, and advice from Vehma/Ford MMLV team*

F. Future Activities / Ongoing Work

- Development of a spectrum analysis to identify a coherent lightweighting strategy adoption path
  - *Prioritize by weight saved, cost of savings, and readiness*
  - *Establish structure for comparing additional proposed strategies*
- Process Technical Cost Modeling
  - *Carbon fiber molding*
  - *Aluminum extruded components*
  - *Magnesium sheet forming*

Response to Previous Criteria

This project was not presented at the 2014 AMR

Conclusion

Mass reduction ~30%

Utilizes:
- Established technologies
- State-of-the-art designs
- Significant power downsizing & luxury decontenting*

Achievable with:
- Moderate price premium
- Low technical risk

**if accepted by the market*

Mass reduction ~40%

Extensive lightweighting needed:
- High-volume production - e.g. Mg (moderate technical risk)
- Automated & rapid cycle time composite forming (high technical risk)

Cost premium remains high until high-volume, low-cost CFCs are available

Mass reduction ~45%

Requires:
- Extensive use of lightweight materials (CFCs, Mg, others)
- Advanced electrical & interior systems

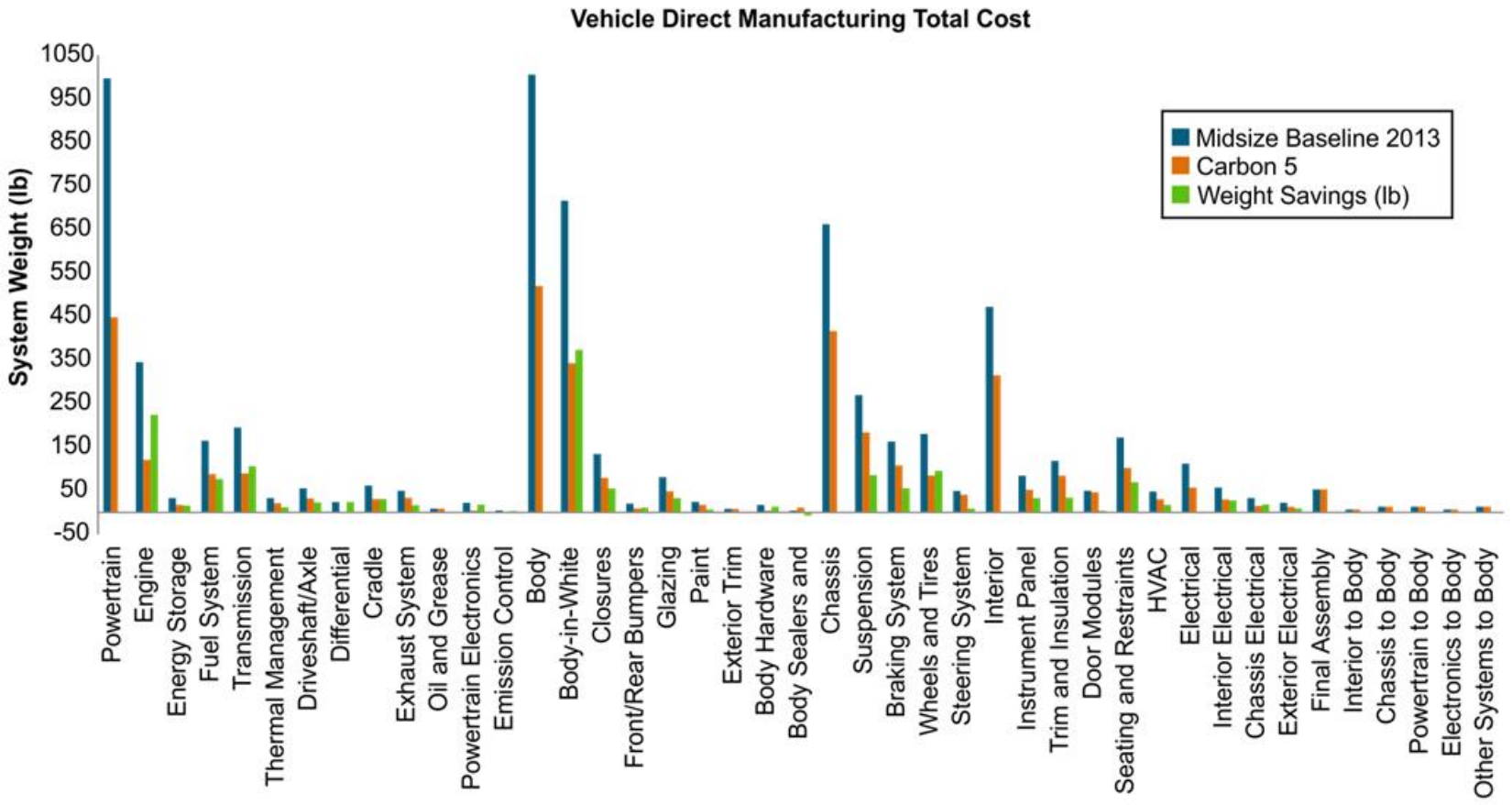
Adjust market expectations of vehicle:
- Performance
- Comfort
- Features

Technical Back-up Slides

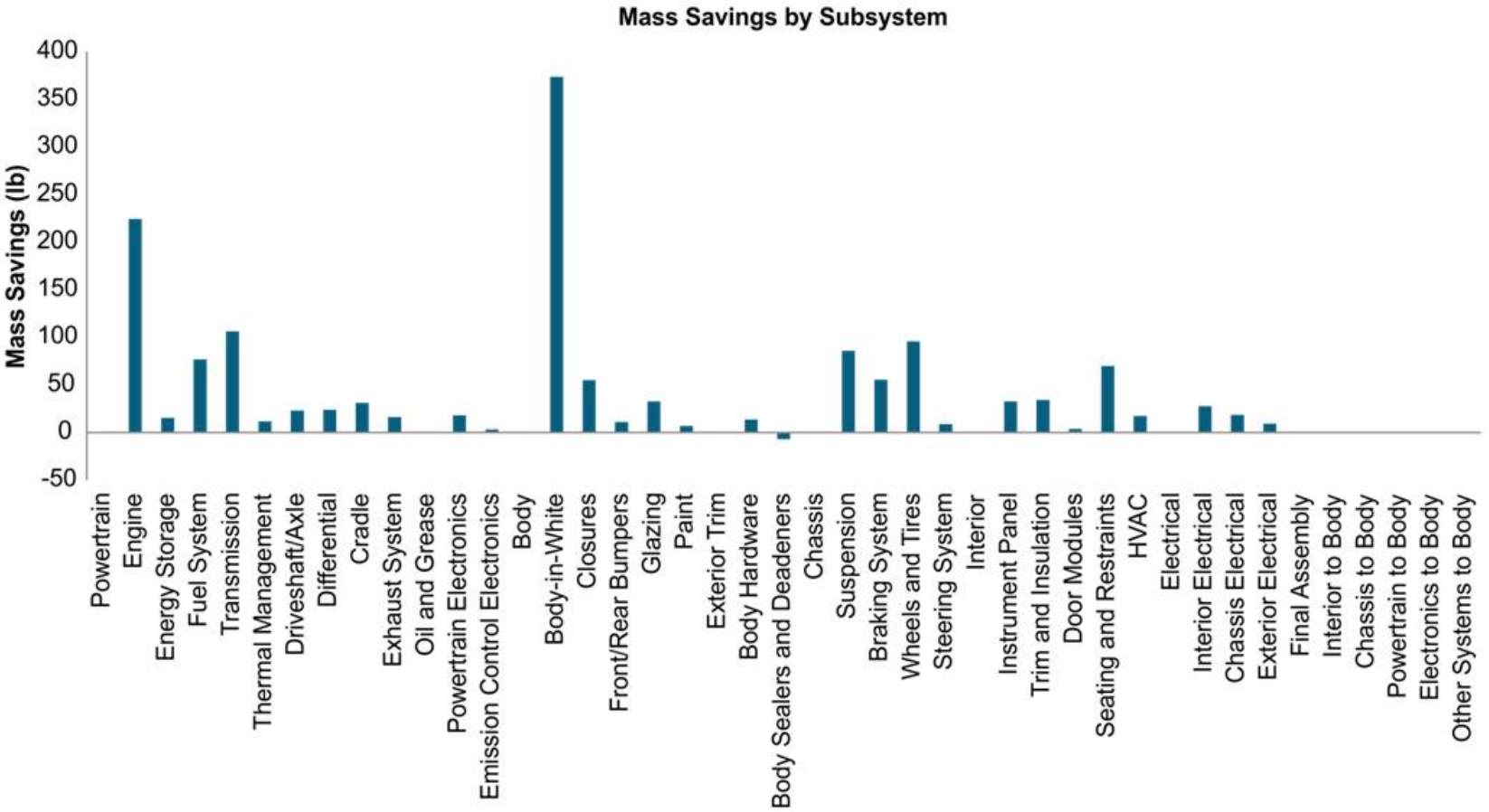
$3.42/lb-saved Target Basis

- Metric provided by DOE at outset of study
- Based on simple payback model
  - *NPV of fuel savings to consumer*
  - *7% reduction in fuel use per 10% weight saved*
  - *15 year life*
  - *10,000 miles average travel per year*
  - *7% annual discount factor*
- Lifetime value of weight savings equates to the cost of 1.1 gallons of gasoline

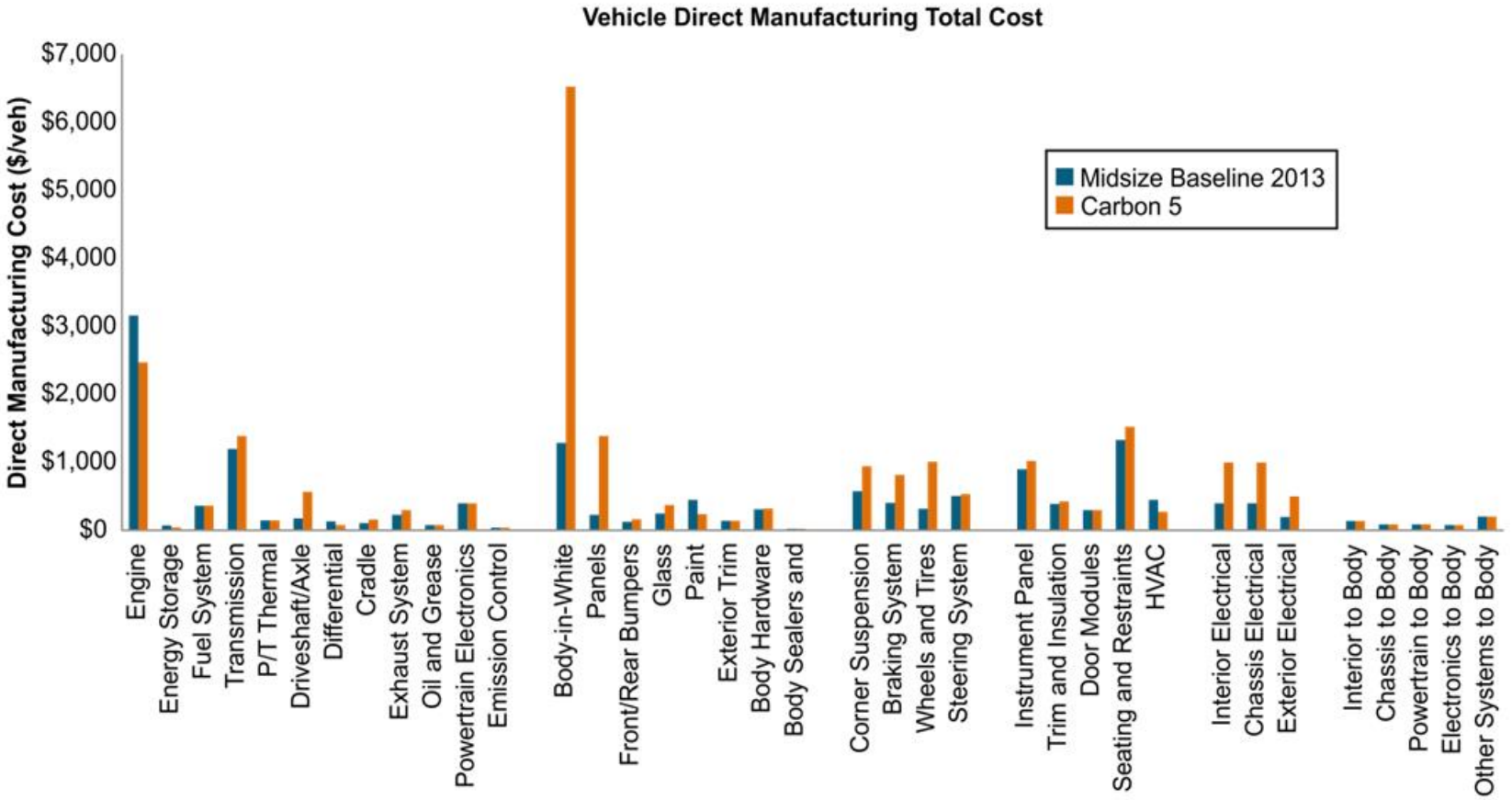
H-3. Results, 45% Mass Reduction Breakdown



H-4. Results, Mass Reduction by System



H-5. Results, Direct Cost Increase by System



H-6. Results, Scenario Savings vs. Target